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Research and Application of Time Workflow Model Based on Timing Constraint Petri Nets

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Abstract

In order to visualize time information of the complex workflow system, time parameter concept is firstly introduced to workflow model, and then a new modeling and time parameters calculating method for the practical business process system are proposed based on timing constraint Petri Nets(TCPN). Finally, an insurance claim process is modeled based on TCPN workflow model, which suggests that it is effective and consistent with the specification of the system requirement.

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1. Introduction

Workflow management technologies have attracted great attention from researchers around the world in recent years. Time information modeling, verification and analysis are the most basic and core problems in Workflow Management System (WFMS)^[1]. Time violations in WFMS can often lead to some negative influences such as increasing cost, unexpected delays and resource wasting, or even cause catastrophic breakdowns within business processes.

A workflow model is used to capture a process abstraction and includes an activity structure and information exchange among activities in a workflow, exception handling, activity duration, and priority

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attributes^[2]. However, there exists no standard for the temporal behavior of workflow modeling. In time modeling of workflow processes, Ling and Schmidt^[3] provided a time interval extension of WF-nets for the purpose of modeling and analyzing time constraint of workflow systems. They emphasized on checking the soundness of workflow process definitions, and endowed an interval for each transition. Eder et al. determined timing inconsistencies at model time and found the optimal workflow execution resources at run time using the time information generated^[4]. Marjanovic assigned a time interval to individual workflow tasks as duration constraints, checked various temporal requirements and inconsistencies of workflow systems by using their proposed verification algorithms^[5, 6].

However, Most of the existing work on time Petri nets have focused on using random variables to describe uncertainty of the workflow time information, or just introduces local time concept, and moreover, most of them do not present the calculation method for the token's time parameters. Therefore, a time constrained workflow model for describing time information of the complex workflow system is presented, and the calculation method for time parameters of TCPN is put forwarded. Finally, a study case is used to illustrate its feasibility.

2. Basic concepts of TCPN

Petri Nets originated from the early work of Car Adam Petri^[7] has the advantages such as formal semantics, local state-based system description, and abundant analysis techniques^[8~10]. Its use as a mathematical foundation for the formal analysis of workflow models is also very attractive. The following concepts will be applied in this paper.

Definition 1. Timing Constraint Petri Nets (TCPN) is defined as a 6-tuple (P, T, F, TC, D, M) : where

P denotes a finite set of places, i.e., $P = \{p_1, p_2, \dots, p_m\}$.

T denotes a finite set of transitions, i.e., $T = \{t_1, t_2, \dots, t_n\}$ and $P \cap T = \emptyset$, $P \cup T \neq \emptyset$.

$F \subseteq P \times T \cup T \times P$, denotes a directed arcs of connecting places and transitions.

$TC: P \cup T \rightarrow R^+ \times R^+$ denotes a set of integer pairs related with places and transitions, remarked by $[TC_{\min}(p), TC_{\max}(p)]$ and $[TC_{\min}(t), TC_{\max}(t)]$ respectively.

D denotes a set of execution durations of transition, remarked by $T_d(t)$.

M is a set of marking with m -vector for describing system state, $\{M(p_1), \dots, M(p_j), \dots, M(p_m)\}$, where $M(p_j)$ denotes the numbers of token in place p_j , M_0 denotes the initial marking.

In general, the time pairs associated with transitions are referred to as transition time pairs and those associated with places are referred to as place time pairs. For the duration times which are associated with transitions like timed Petri nets do, we say they are transition durations. For those places and transitions without explicit timing constraints, the default values of place time pairs or transition time pairs are (zero, infinity) and the default value of transition duration is zero.

Definition 2. Workflow model is a set of activities abstracted from actual business process, which is often used to define concrete workflow. It includes all kinds of information needed by workflow when being executed.

Definition 3. A Petri-net $PN=(P, T, F)$ is called a WorkFlow net(WF-net) if:

(1) PN has two special places: i and o . Place i is a source place, namely $\square i = \emptyset$. Place o is a sink place, namely $o \square = \emptyset$.

(2) If we add a transition t^* to PN so that $\square t^* = \{o\}$ and $t^* \square = \{i\}$, then the resulting Petri-net is strongly connected.

To specify the timing constraints, WF-net is extended with time information, leading to Timing Constraint WorkFlow net(TCWF-net). Here, two kinds of timing constraints should mainly be discussed: internal and external ones as shown in the following.

Definition 4. Activity internal time constraint, which is managed by a resource agent (e.g., a software system or human) that is responsible for the enactment of an activity, is embedded in the description of every individual activity. It includes the defined execution duration and executable time span of this activity. It is important to address the issues of how to verify the correctness of a timed workflow model and select rationally the time parameters at the build-time to realize efficient workflow management.

Definition 5. Activity external time constraint, which follows implicitly from control dependency of a workflow schema, causes the buffer time that is handled by a workflow manager or engine. For example, an activity can only start five minutes after its preceding activities end, or it must start ten minutes after another specific activity ends. To specify this kind of timing constraints, we use the concepts of lower bound constraint, denoted by $t_l(A, B)$ and upper bound constraint, denoted by $t_u(A, B)$ respectively.

3. Construction of Timing Constraint Workflow Model

3.1. The mapping rules of timing constraint workflow model

In order to incorporate necessary time information into a workflow model, we have introduced internal and external time constraint. The former is referred to an execution duration and executable time span, where the executable time span managed by a responsible resource agent ranges from the time of task allocation to allowable latest completion time. Given a workflow model, designers can assign execution duration and executable time span (during which an activity can be executed) to every individual activity based on their experiences and expectations from the past execution. The latter represents the temporal dependency relations between different activities.

When we model the time information of a complex activity, the mapping rules of time constraint appended to design activity are as follows:

(1) Activity internal time constraint is mapped to time pair of transition t , i.e., $[TC_{\min}(t), TC_{\max}(t)]$. If transition t has no time constraint, time pair of transition t is $[0, +\infty)$, the execution duration of activity is mapped to time delay of transition t , i.e., $T_d(t)$.

(2) Assuming that there are transition t_A and transition t_B corresponding to activity A and activity B, and p_B which connects t_A and t_B , time constraint between A and B is mapped to time constraint pair $[TC_{\min}(p_B), TC_{\max}(p_B)]$ which are divided into three classes: lower bound time constraint, i.e., time pair of p_B is $[t_l(A, B), +\infty)$, upper bound time constraint, i.e., time pair of p_B is $[0, t_u(A, B)]$, both of them exist, i.e., time pair of p_B is $[t_l(A, B), t_u(A, B)]$.

3.2. Time parameter calculation of timing constraint workflow model^[1,11]

Fig.1 shows a basic workflow fragment of TCPN, where time pairs $[TC_{\min}(p_1), TC_{\max}(p_1)]$ and $[TC_{\min}(p_2), TC_{\max}(p_2)]$ denote the time period during which p_1 's or p_2 's succeeding activities are enabled after a case arrives at p_1 or p_2 .

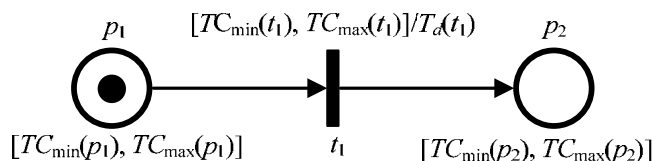


Fig. 1 A basic fragment of TCPN

For instance, if place p_1 gets a token in time T_0 , t_1 is enable during the time interval $(T_0+TC_{\min}(p_1), T_0+TC_{\max}(p_1))$. $[TC_{\min}(t_1), TC_{\max}(t_1)]/T_d(t_1)$ denotes the time period during which the activity corresponding to t_1 can be executed after it is enabled. $[TC_{\min}(t_1), TC_{\max}(t_1)]$ represents the firing time pair of t_1 , $T_d(t_1)$ represents the execution duration of t_1 . If transition t_1 is enabled at T_1 , then it can be fired within the absolute interval $(T_1+TC_{\min}(t_1), T_1+TC_{\max}(t_1))$. Thus, $(T_1+TC_{\min}(t_1), T_1+TC_{\max}(t_1))$ is called an absolute execution interval of t_1 , where T_1 denotes when t_1 is enabled.

For facilitating analysis, we use $T_{EE}(t)/T_{LE}(t)$ for denoting the earliest/latest enabling time, $T_{EF}(t)/T_{LF}(t)$ for denoting the earliest/latest firing time, $I_p(t)/O_p(t)$ for denoting the set of input/output places of transition t , $I_p(p)/O_p(p)$ for denoting the set of input/output transitions of place p ; $T_a(p)/T_r(p)$ is the time at which a token arrives at/is removed from a place p .

In order to analyze the schedulability for a transition t , it firstly needs to compute some relative time parameters such as the time pair $T_{EE}(p)/T_{LE}(p)$, $T_{EE}(t)/T_{LE}(t)$, etc. Considering the global time of workflow instances, and according to the literature^[12], we have the following formulae:

$$[T_{EB}(t), T_{FE}(t)] \subseteq [T_{EF}(t), T_{LF}(t)] \subseteq [T_{EE}(t), T_{LE}(t)] \quad (1)$$

$$T_i(p) = \min\{T_{FE}(t_i)\}, t_i \in O_p(p) \quad (2)$$

$$T_a(p) = \min\{T_{FE}(t_i)\}, t_i \in I_p(p) \quad (3)$$

$$T_{FE}(t) - T_{EB}(t) = T_d(t) \quad (4)$$

Assuming p_i is the input place of transition t_i , p_o is the output place of t_i , and we can get the calculating method of some related time parameters as follows:

(1) Enabling time pairs of token

Taking place p_i as an example, we use $[T_{EE}(p_i), T_{LE}(p_i)]$ to denote the enabling time pair of p_i , where $T_{EE}(p_i)/T_{LE}(p_i)$ is the earliest/latest enabling time of p_i , then the calculation formulae is

$$T_{EE}(p_i) = T_a(p_i) + TC_{\min}(p_i) \quad (5)$$

$$T_{LE}(p_i) = T_a(p_i) + TC_{\max}(p_i) \quad (6)$$

(2) Enabling time pairs of transition

We use $[T_{EE}(t_j), T_{LE}(t_j)]$ to denote the enabling time pair of transition t_j , where $T_{EE}(t_j)/T_{LE}(t_j)$ is the earliest/latest enabling time of t_j and $p_i \in I_p(t_j)$, then the calculation formula is

$$T_{EE}(t_j) = \max\{T_a(p_i) + TC_{\min}(p_i)\} \quad (7)$$

$$T_{LE}(t_j) = \min\{T_a(p_i) + TC_{\max}(p_i), T_a(p_i) + TC_{\min}(p_i) + TC_{\max}(t_j)\} \quad (8)$$

(3) Firing time pairs of transition

We use $[T_{EF}(t_j), T_{LF}(t_j)]$ to denote the firing time pair of transition t_j , where $T_{EF}(t_j)/T_{LF}(t_j)$ is the earliest/latest firing time of t_j and $p_i \in I_p(t_j)$, then the calculation formula is:

$$T_{EF}(t_j) = T_{EE}(t_j) + TC_{\min}(t_j) = \max\{T_a(p_i) + TC_{\min}(p_i)\} + TC_{\min}(t_j) \quad (9)$$

$$T_{LF}(t_j) = T_{LE}(t_j) = \min\{T_a(p_i) + TC_{\max}(p_i), T_a(p_i) + TC_{\min}(p_i) + TC_{\max}(t_j)\} \quad (10)$$

4. A Case Study

Now we use an example to illustrate the application of our approach. Fig.2 is a workflow model based on TCPN for describing the process of insurance claim. It is a non-conditional WF-net; all the transitions corresponding to activity are listed in Table 1. The imposed timing constraints of place and transition are specified by the business requirement of insurance claim or the experience of insurance agent, and the unit of time is minute. For any places or transitions which have non-explicit time constraints, the default value of a time pair is (zero, infinity) and the default value of transition duration is zero.

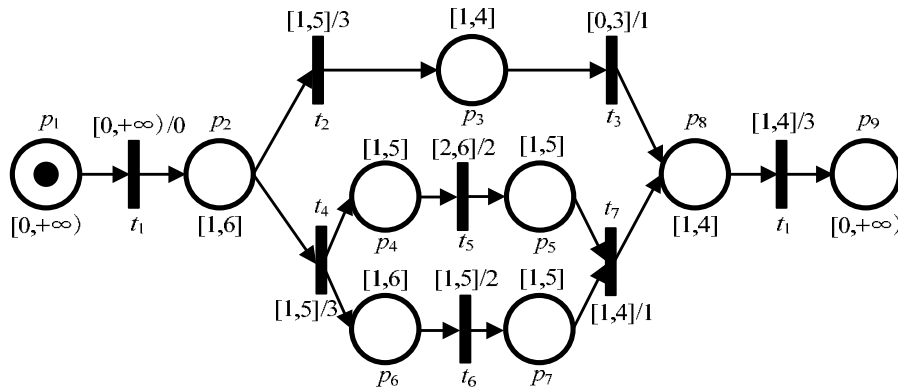


Fig.2 modeling of insurance claim process based on TCPN

Table 1. The operational semantics of the transitions

Transition t_j	Operation	$T_d(t_j)$
t_1	Register	0
t_2	Send rejection	3
t_3	Record rejection	1
t_4	Count compensation	3
t_5	Send compensation	2
t_6	Send letter	2
t_7	Record rejection	1
t_8	Archive rejection/compensation	2

Suppose that there is a token in place p_1 in the beginning, and the token represents one insurance claim case. t_1 has no time constraint, so we take the fire ending time of t_1 , i.e., $T_{FE}(t_1)$ as the origin of coordinate, and make schedulability analysis of the successor transitions in this TCPN-net model. $T_{FE}(t_1)$ may be the relative time corresponding to the arriving time of the case or the absolute time. t_2 and t_4 are in conflict structure, namely we should make sure either archive compensation or archive rejection according to the attributes of case.

5. Conclusion

In this paper, time parameter concept is firstly introduced to workflow model, and the analysis on time performance of workflow is one of the most important research topics. Next, a new modelling method for time information of the complex workflow system is proposed based on TCPN. Finally, an example of insurance claim is used to verify the correctness and validity of the proposed approach. It should be mentioned that the proposed modelling method has rich semantics of time and important reference value in enriching the theory of distributed workflow modelling in WFMS, which can be also widely used and applied to the development of workflow management software.

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References

- [1] LI H.F., FAN Y.S. Workflow model analysis based on Time Constraint Petri Nets. *Journal of Software*, 2004, 15(1): 17-26.
- [2] Mentzas G., Halaris C., Kavadias S. Modeling business processes with workflow systems: an evaluation of alternative approaches. *International Journal of Information Management*, 2001, 21:123-135.
- [3] Ling S., Schmidt H. Time Petri nets for workflow modeling and analysis. In: *Proc. of IEEE International Conference on System, Man and Cybernetics*, 2005, pp.3039-3044.
- [4] Eder J., Panagos E., Pozewaunig H., et al. Time management in workflow systems. In: Abramowicz W, Orlowska ME, eds. *Proc. of the 3rd International Conference on Business Information Systems*. Heidelberg, London, Berlin: Springer-Verlag, 1999, pp.265-280.
- [5] Marjanovic O., Orlowska M.E.. On modeling and verification of temporal constraints in production workflows. *Knowledge and Information Systems*, 1999, 1(2): 157-192.
- [6] Marjanovic O. Dynamic verification of temporal constraints in production workflows. In: *Proc. of the 11th Australasian Database Conf. (ADC2000)*. Canberra, 2000, pp.74-81.
- [7] Petri C.A. "Kommunikation mit Automation" Ph.D. dissertation, University Bonn, Bonn, Germany, 1962.
- [8] Van der Aalst W.M.P. The application of Petri nets to workflow management. *Journal of Circuits, Systems, and Computers*, 1998, 8 (1): 21–66.
- [9] Van der Aalst W.M.P. Flexible workflow management systems: an approach based on generic process models. *Lecture Notes in Computer Science*, 1999, 1677:186–195.
- [10] Van der Aalst W.M.P., Ter Hofstede A.H.M., Kiepuszewski B., et al. Workflow patterns. *Distributed and Parallel Databases*, 2003, 14(1):5–51.
- [11] Li J.Q., Fan Y.S., Zhou M.C. Timing constraint workflow nets for workflow analysis. *IEEE Trans. on Systems, Man, and Cybernetics*, 2003, 33(2): 179-193.
- [12] Tsai J.J.P., Yang S.J., Chang W.H. Timing constraint Petri nets and their applications to schedulability analysis of real-time system specifications. *IEEE Trans. on Software Engineering*, 1995, 21(1):32–49.